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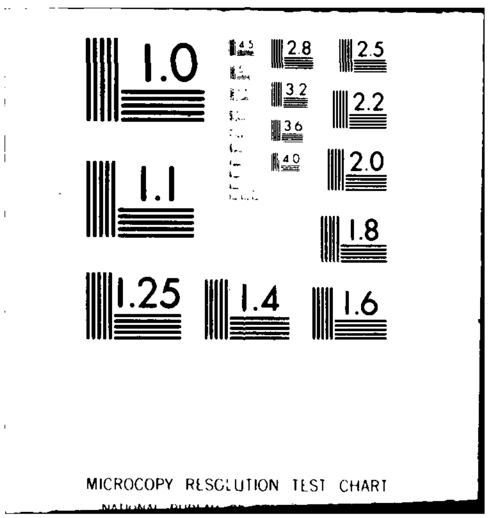
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SHOCK TUBE FLOW UNIFORMITY EXPERIMENTS

AD A090349

Science Applications, Inc.
101 Continental Blvd., Suite 310
El Segundo, California 90245

23 September 1979

Final Report for Period 3 May 1979—13 June 1979

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Shock Tube Diagnostics; Image Converter; Framing Camera

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of experiments was performed in the NASA Ames Electric Arc Shock Tube to investigate the uniformity of the shock heated flow field. The experiments were designed to record the flow field about cone and wedge probes. Shock angles were obtained from high speed, image converter framing camera images throughout the first 30 μsec of shock heated flow and used to determine the corresponding pitot pressure.

20. ABSTRACT (Continued)

+ or -

The measured Mach angles all fall between 28 and 32 degrees; because of flow field distortion of the optical image, the measurement accuracy was ±2 degrees. For a static pressure of 2,200 psi, the pitot pressure corresponding to the measured Mach angle is 5,910 psi ± 600 psi.

Flow field distortion of the optical image may have been caused by recessed flat windows; additional experiments using flash windows are recommended.

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PREFACE

This program was conducted for the Defense Nuclear Agency under contract number DNA001-79-C-0329 to provide flow uniformity data for the NASA Ames electric arc shock tube. The effort was sponsored by the Strategic Structures Division of the Shock Physics Directorate and was performed during the period 3 May 1979 to 13 June 1979. Dr. George Ullrich was the DNA Technical Representative.

The SAI program manager was Dr. James Craig who with the assistance of Mr. Ernie Lahti conducted the shock tube experiments and reduced the data.

We are grateful to Mr. Robert E. Dannenberg of the NASA Ames Research Center and to Mr. Joe Orwen and Mr. Frank Cosell of Marco Scientific for their continuing assistance and cooperation.

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1.0 INTRODUCTION

In the 1978 Mighty Mach Field test series, pitot pressure measurements were recorded in the high pressure region. Shock tube calibration of the pitot probes was performed in the NASA AMES arc driven shock tube at an incident shock pressure of 1,100 psi. However, stagnation pressures determined from gage records and static calibration factors disagreed with theoretical stagnation pressure by about ±15%; and in addition, the stagnation pressure measurements made with PCB 113M gages fell off as much as 25% before contact surface arrival. There are a number of possible error sources; including thermal and mechanical effects in the gage, flow changes in the shock tube caused by the diaphragm proximity (L/D = 22) or boundary layer induced two-dimensional effects.

A program was conducted to determine the uniformity of the shock heated flow in the NASA/Ames Electric Arc Shock Tube (EAST) by observing the flow field about conical and wedge probes. Shock angles were obtained from high speed framing camera images throughout the first 30 μsec of the shock heated flow.

2.0 ANALYSIS

With a conical probe mounted on the axis of the shock tube, a stationary conical shock wave is created in the flow behind the moving shock wave. For cone half angles up to 8 degrees, the shock angle varies little from the Mach angle, α. The Mach angle and number, M, are related by

$$\sin\alpha = \frac{1}{M} \tag{1}$$

When the static or side wall pressure, p_S, is measured, and flow Mach number is determined from the measured Mach angle, the stagnation pressure, p_T, can be calculated from the isentropic flow relation

$$p_T/p_S = \left(1 + \frac{\gamma-1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} \tag{2}$$

where γ=1.3 is the real gas specific heat ratio. For supersonic flows, the bow shock on the pitot probe reduces the stagnation pressure. The pitot pressure to static pressure ratio is

$$p_{T2}/p_S = \left(\frac{\frac{\gamma+1}{2} M^2}{2}\right)^{\frac{\gamma}{\gamma-1}} \Bigg/ \left(\frac{2\gamma}{\gamma+1} M^2 - \frac{\gamma-1}{\gamma-2}\right)^{\frac{1}{\gamma-1}} \tag{3}$$

Therefore, with measurements of the wall pressure and Mach angle, the pitot pressure can be calculated. For the nominal calibration condition, M_2 = 1.85, the stagnation pressure can be determined within eight percent if the Mach angle is measured within one degree.

3.0 EXPERIMENTS

Shock tube experiments were conducted in the NASA Ames East facility. Wedge and conical probes were designed to adapt to the BRL pitot probe strut used in previous calibrations. The probes and strut were mounted at Station 22 (Figure 1) in Test Section No. 2 which has 75mm diameter ports in the side-wall. The 75mm diameter acrylic windows were 38mm thick to be retained by a window frame with a 50mm viewing aperture for strength requirements. The flat windows were mounted tangent to the internal diameter of the shock tube leaving the upper and lower portions of the window recessed.

The optical system had the capability of producing eight shadowgram images with 5 microsecond spacing using an image converter camera (IMACON) and an argon laser light source (Figure 2). The argon laser and collimating optics were installed near the end of the shock tube where the power for the laser power supply was located. The 50mm collimated laser beam passed about 15 meters along the shock tube to a mirror where it was turned through the test section. Focusing and reducing optics were required to image the test section onto the 8mm photo cathode tube, and a laser line filter ($\lambda \approx 5145Å$) was used to block flow luminosity. A mechanical shutter was used over the photocathode tube, because it cannot safely absorb continuous high intensity illumination.

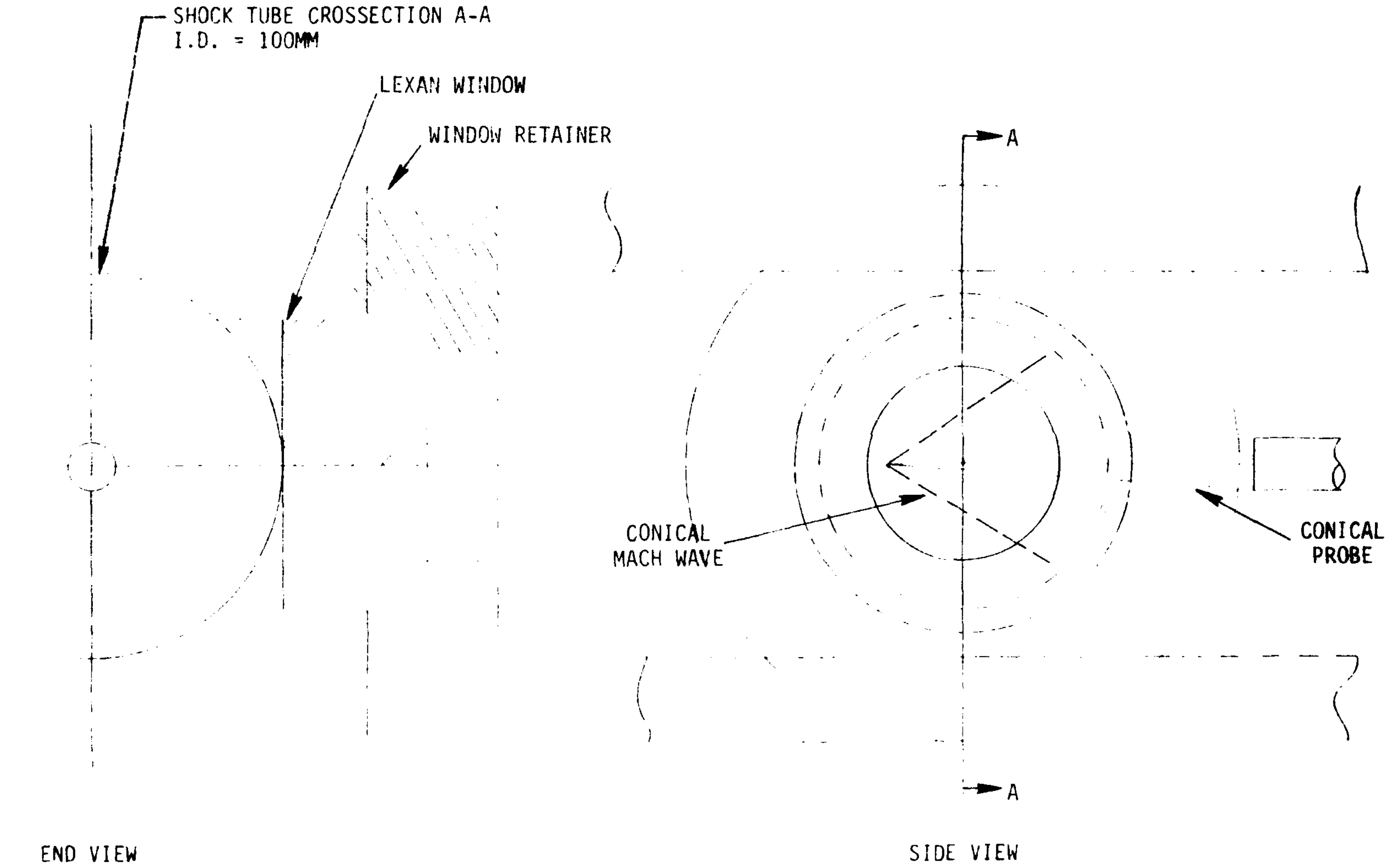

Figure 1. Conical Probe and Window Installation Schematic

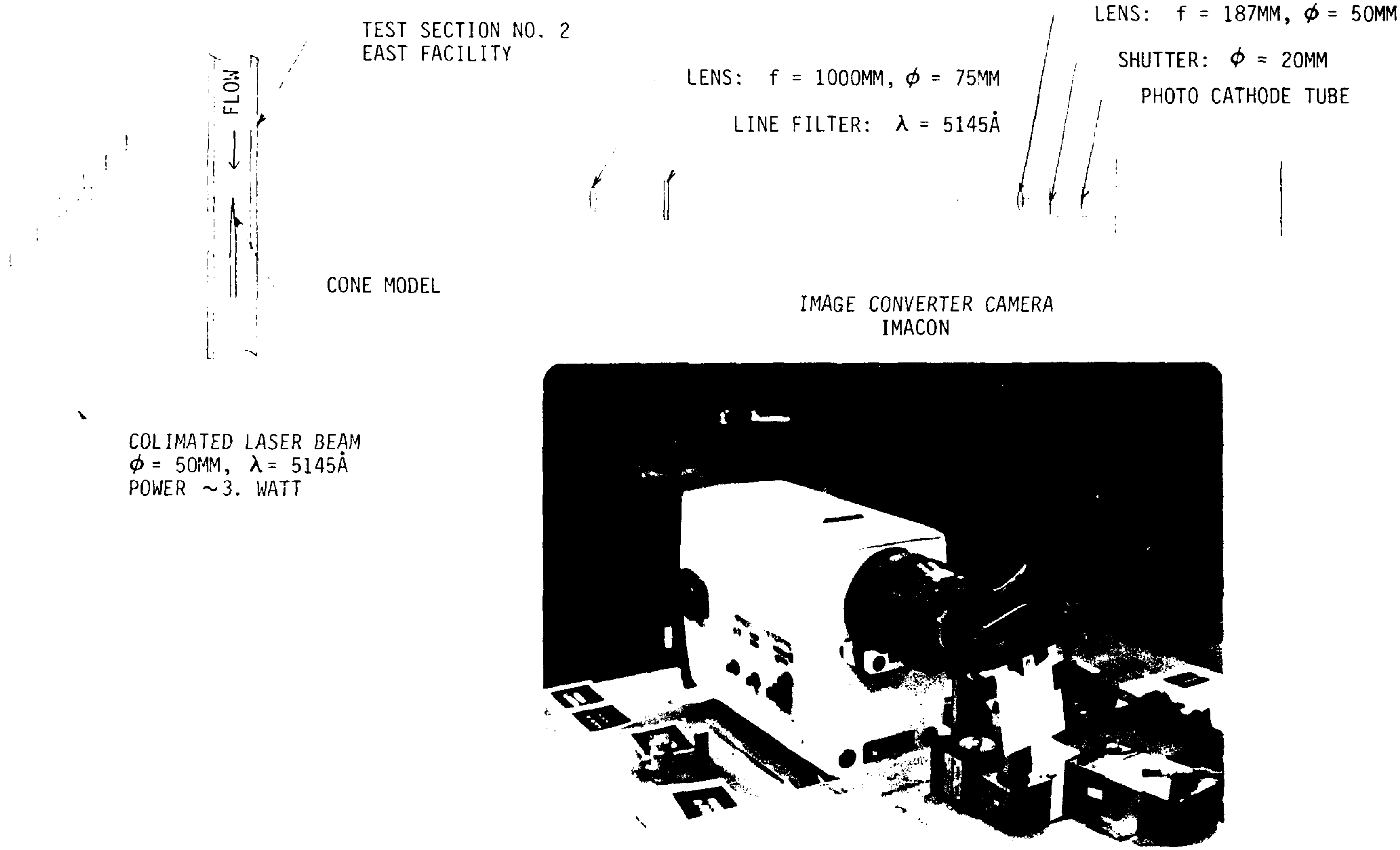

FIGURE 2. OPTICAL SYSTEM INSTALLATION

4.0 TEST SUMMARY

Run 1 (5/23/79) - The first run was a check out run of the mechanical shuttering system. Shutter operation was monitored with an optical detector in place of the camera which was being adjusted at Marco Scientific. Oscilloscope records of the detector output showed that the shutters had operated at the correct time with respect to shock wave arrival in the test section. Pressure records showed that the shock tube reproduced the BRL test condition of Δp = 1,100 psi at the test section.

Run 2 (5/29/79) - Before the second run, a conical needle probe with a stainless steel tip arrived from Experimental Engineering, Inc. (EEI) and the IMACON camera was delivered from Marco Scientific. The camera and a fast rise time trigger coupler were installed in the EAST facility by Marco Scientific. No optical data was obtained in the second shot due to a mechanical shutter failure.

Run 3 (5/31/29) - The shutter problem was corrected for the third shot in which the IMACON and mechanical shutters were triggered correctly. An enlargement of the eight frame record is shown in Figure 3. The frame exposure time was 1 μs, and the frame spacing time was 5 μs. The IMACON was triggered before the main shock wave reached viewing port. For frames two through four, the main shock is visible in the viewing port. Although the images are distorted, the Mach waves from the conical probe are faintly visible in frames four through six. Due to a faulty tube, the IMACON was not imaging correctly which caused portions of the seventh and eighth frame to be obscured.

Run 4 (6/5/79) - The defective tube was replaced by Marco Scientific. The IMACON was triggered correctly and recorded eight frames of the flow field (Figure 4). Again the

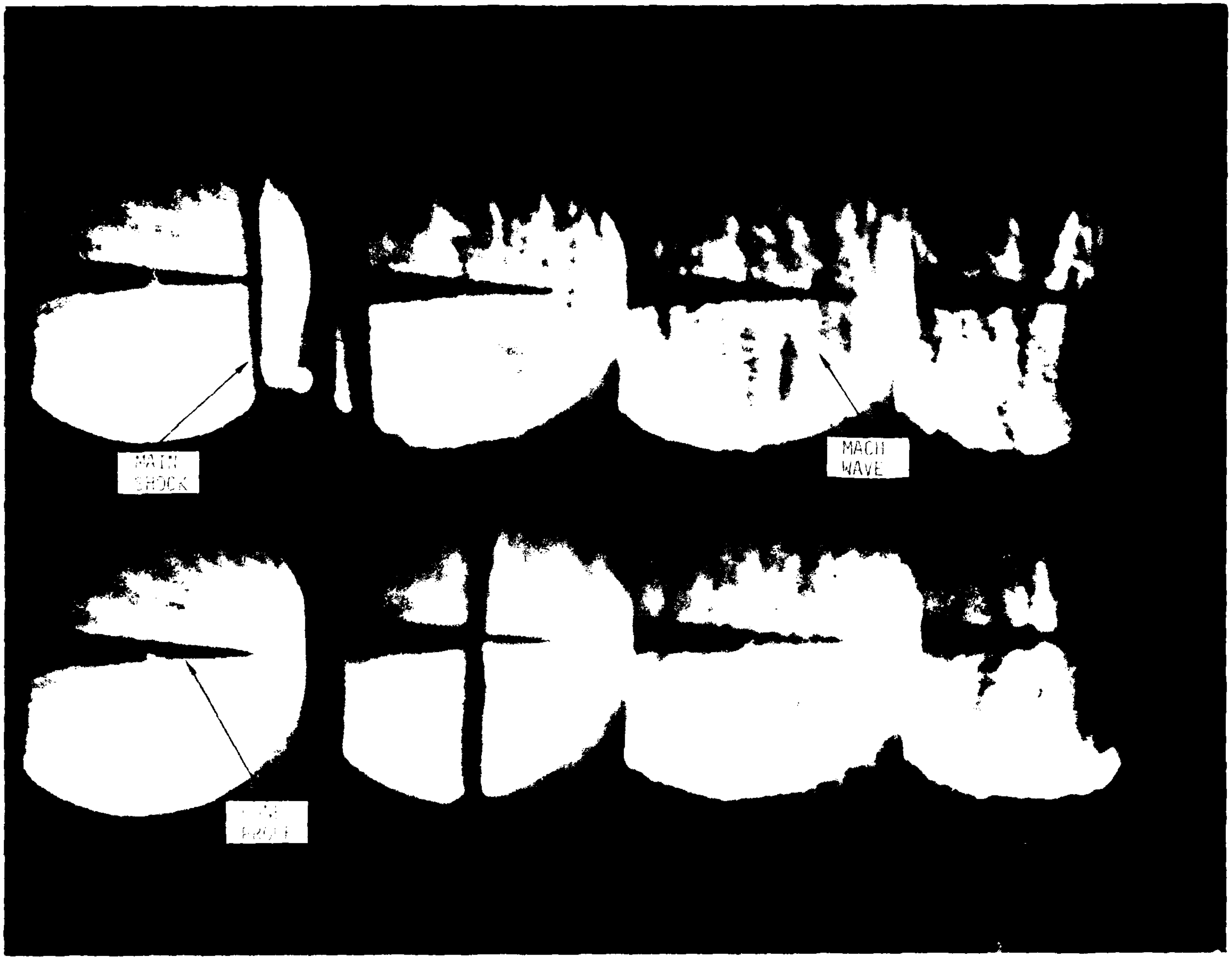

FIGURE 3. IMACON SHADOWGRAM RECORDS OF CONICAL FLOW FIELD - RUN 3

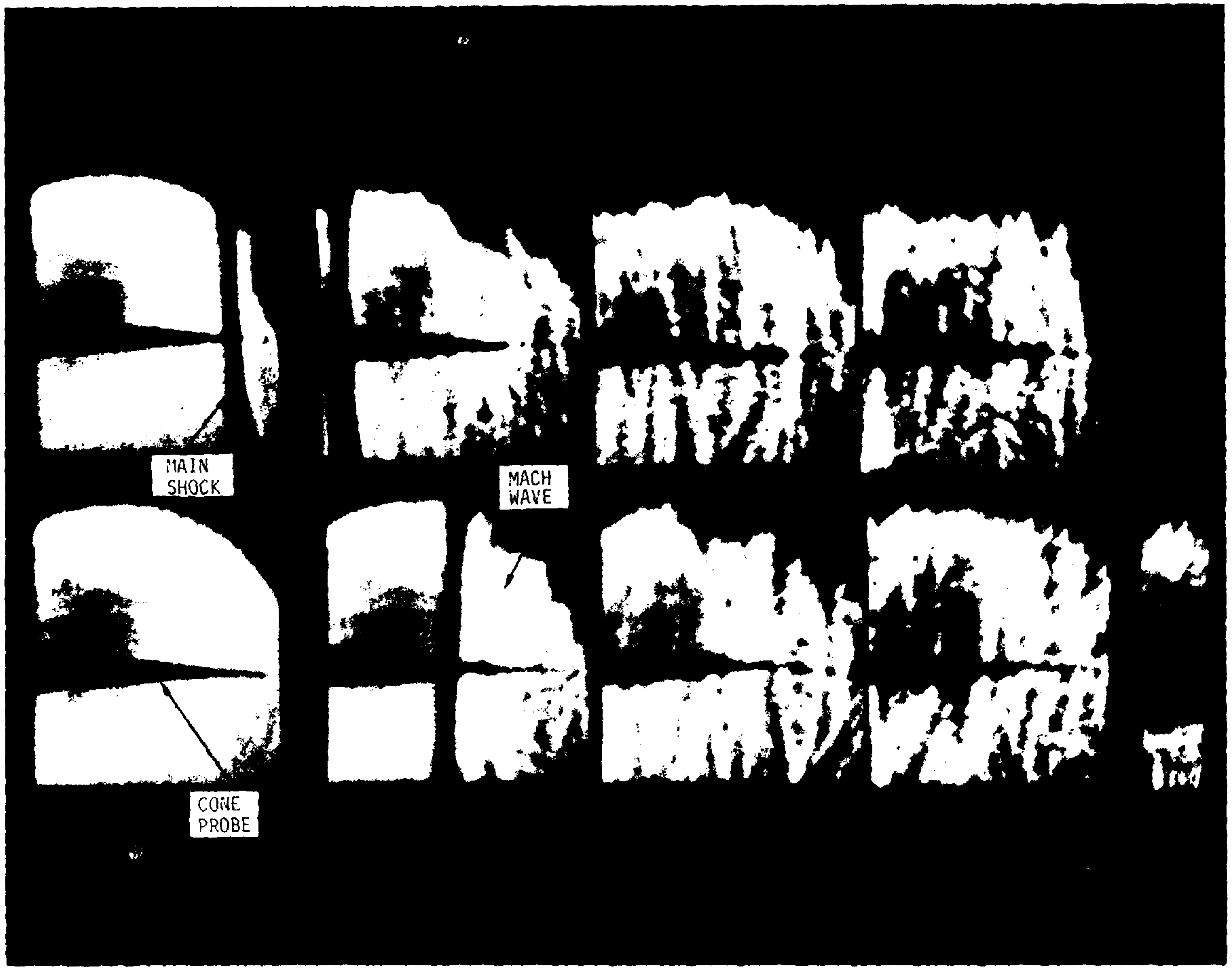

FIGURE 4. IMACON SHADOWGRAM RECORDS OF CONE FLOW FIELD - RUN 4

IMACON was triggered before the main shock reached the viewing port and is visible in the viewing port for frames two through four. Even though the distortion is still severe, the Mach waves are faintly visible in frames two through four. The distortion in frames five through eight is quite severe, and the Mach waves are not visible. The distortion appears to have a vertical orientation and changes between frames; hence, it is assumed to be caused by the flow field. The recessed portion of the optical ports cause disturbances on each side of the shock tube which were not expected to be this significant. Flow field non uniformity is not expected in the center of the shock tube; however, non ideal effects caused by diaphragm proximity (L/D $\sim$ 22) may be important.

Run 5 (6/6/79) - A wedge probe was installed to increase flow field definition, and the shock tube and IMACON operated correctly. Again, the main shock is visible in frames two through four (Figure 5). Two dimensional Mach waves are observed in frames three through eight. Although the wedge probe produces a more visible Mach wave, the flow field distortion still mottled its image. A reflected wave can be seen moving downward in the top portion of frames five through eight.

A facility problem with a high voltage (80 kv) relay in the capacitor bank occurred on 6/7/79 while attempting Run 6. The capacitor bank switching system was repaired and tested by 6/14/79 when BRL personnel began making pitot probe calibrations.

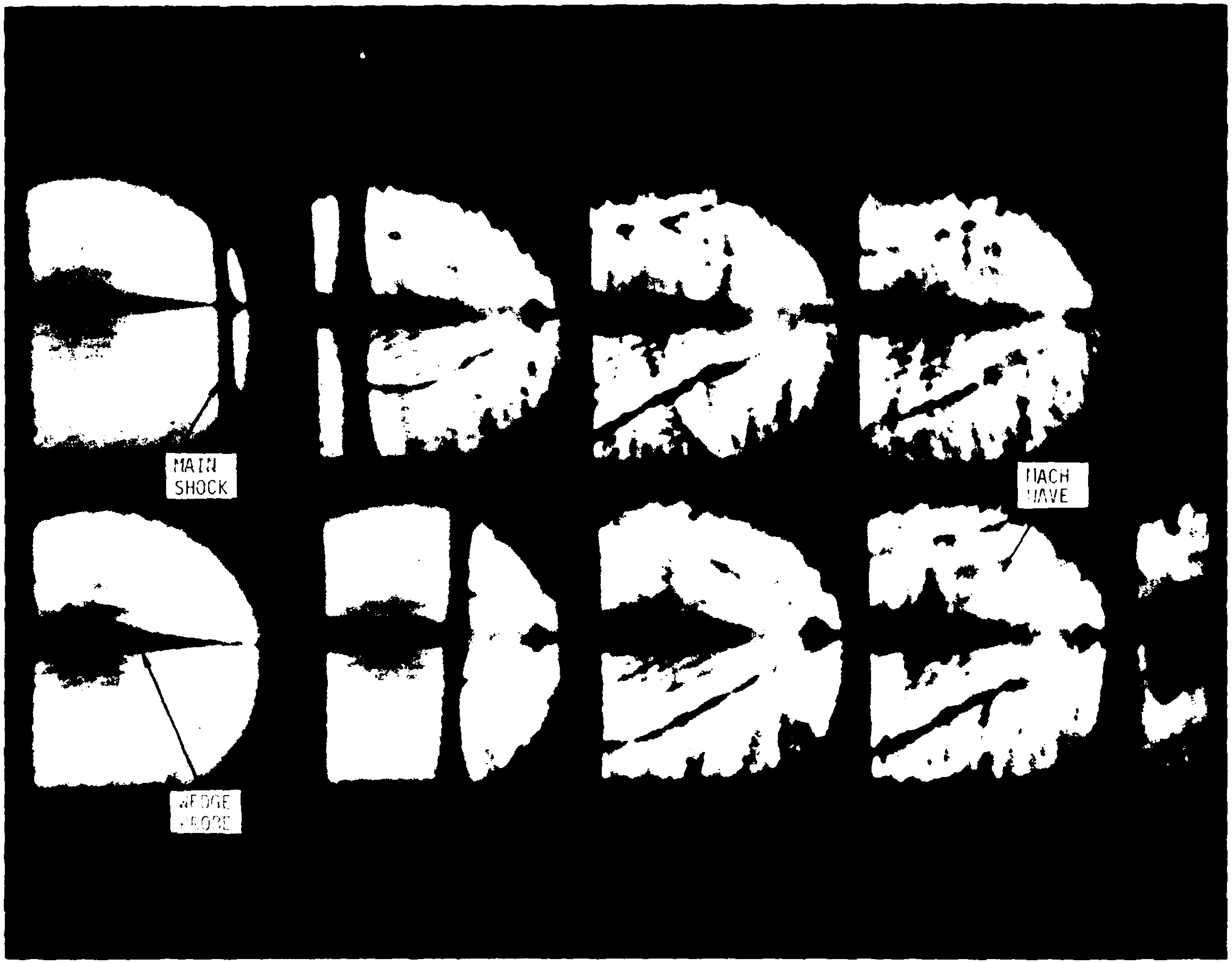

FIGURE 5. IMACON SHADOWGRAM RECORDS OF WEDGE FLOW FIELD - RUN 5

5.0 RESULTS AND CONCLUSIONS

An attempt was made to determine the Mach angles in the flow field images. The measurement accuracy (±2 degrees) was not adequate enough to determine the pitot pressure much closer than had been determined from BRL pitot gage records using static calibrations.

The measured angles from Run 5 all fell between 28 and 32 degrees indicating a flow Mach number of 2.0 ± 0.12. For a static pressure of 1,100 psi, the corresponding pitot pressure is 5,910 psi ± 600 psi. Therefore, with the existing Mach angle measurement accuracy, the pitot pressure or its variation with time cannot be determined any better than ±10%.

Although the current images display a noisy flow field, the distortion is probably caused by the recessed flat windows. Therefore, additional experiments using flush windows with a round internal surface should be performed. For these experiments, single exposure recording should be used until acceptable resolution and accuracy is obtained.

Single frame recording could be performed with the Ames Beckman and Whitly Image Converter Camera which uses a point sparklight source, or with a pulsed laser shadowgram system.

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